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HUMAN INFORMATION HANDLING PROCESSES

Arthur W. Melton

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13. ABSTRACT

This report lists the products of the contract work: 12 published technical reports reflecting work on this contract and earlier Contract No. AF49(638)1235; 57 technical reports published, 3 technical reports in press, 9 technical reports submitted for publication as of 31 August 1971, and 47 oral presentations at scientific meetings. Major accomplishments are summarized under the general headings: taxonomy of information handling processes, (b) short-term memory, and (c) storage and retrieval of information from memory.

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PART I

OBJECTIVES OF THE CONTRACT PROGRAM

This is the Final Report of research supported by the Advanced Research Projects Agency, United States Department of Defense, and monitored by the Air Force Office of Scientific Research, under Contract AF 49(638)-1736, with the Human Performance Center, Department of Psychology, University of Michigan. The period of this contract work was from 1 June 1967 through 31 August 1971.

This contract continued the research program on Human Performance in Information Handling and Storage, which extended from 1 Jun 1963 through 31 May 1967 under Contract No. AF 49(638)-1235. One of the general objectives of the original contract and the present contract was to establish, in a University environment, a permanent research facility for the investigation of human performance capabilities and limitations that are of importance for the performance of men in a wide variety of man-machine systems. With the support for such an effort by these contracts, the Human Performance Center of the Department of Psychology, University of Michigan, was established in 1963 and has now become a stable federation of experimental and mathematical psychologists interested in advancing knowledge about man's information processing activities in sensing, perceiving, remembering, skillful manipulation of controls, and problem solving. The effort within this contract program has been directed more and more to the perceiving and remembering functions, with increasingly heavy emphasis on cognitive and intellectual factors and skills.

The specific objectives of research under Contract No. AF 49(638)-1736 are stated as follows in the Contract:

a. Taxonomy of information handling processes. This effort will seek to improve knowledge of the ways of classifying types of information and information inputs, storage and processing activities required, and types of measures of outputs relevant to information processing systems.

b. Selective information handling processes. This will include research on searching, filtering, transmitting, and condensing information and on human adaptive capacities in optimizing performance relative to the probability and significance of information components.

c. Information storage and retrieval (memory). This will include work on development of a quantitative model of human short-term memory, resolution of critical issues in the theory of human memory, refinement of short-term memory methods and measures, and determination of the contribution of short-term memory to performance in information processing and decision-making tasks.

d. Work on the organization and synthesis of knowledge regarding human information handling processes.

Publications, papers presented at scientific meetings, and major accomplishments toward these objectives are reported in Part III, entitled "Technical Program." The scientific personnel who participated in and contributed to this research program are listed in Part II, entitled "Participating Scientists."

PART II

PARTICIPATING SCIENTISTS

The accomplishments of this project reflect the individual and joint efforts of many individuals. The key scientists in the project were, of course, the Senior Staff who initiated and conducted sub-programs of research and served advisory or supervisory functions for visiting post-doctoral scientists and for graduate students who chose to work on problems within the scope of the project. Twenty graduate students completed doctoral dissertations on problems of central importance to the project. A listing of the participants in the project in these several categories is included in the following sections as an acknowledgement of their contributions over and above such acknowledgement as appears in the list of technical reports and reports to scientific meetings, which appears in Part III.

Senior Staff

All members of the senior staff of the project have been members of the Human Performance Center and full-time members of the faculty of the Department of Psychology. They are listed in Table 1 together with their periods of active involvement in the project.

Table 1

Senior Staff of the Project

Name	Work Period on the Contract
Robert A. Bjork (Ph.D., Stanford U., 1966) Assoc. Prof.	1 Jun 67--31 Aug 69 1 Jan 70--31 Aug 70
James G. Greeno (Ph.D., U. Minnesota, 1961) Professor	1 Jun 69--31 Aug 71
Judith P. Goggin (Ph.D., U. Cal., Berkeley, 1964) Asst. Prof. (Now Assoc. Prof., U. Texas, El Paso)	1 Jun 67--31 Aug 69
Edwin J. Martin (Ph.D., U. Iowa, 1963) Professor	1 Jun 67--31 Aug 71
Arthur W. Melton (Ph.D., Yale U., 1932) Professor and Principal Investigator	1 Jun 67--19 Jul 68 1 Jan 69--31 Aug 71
Robert G. Pachella (Ph.D., John Hopkins, 1970) Asst. Prof.	1 Jul 70--31 Aug 71
Richard W. Pew (Ph.D., U. Michigan, 1963) Professor	1 Jun 67--31 Aug 70 1 Aug 71--31 Aug 71

Visiting Scientists

A number of post-doctoral scientists visited the Human Performance Center for periods of time ranging from a summer to a year, and participated in the sub-programs of research on the project in collaboration with one or more of the senior staff. In some cases the project supplied partial salary support of these visiting scientists; in other cases the support was limited to resources, equipment, and materials necessary for the conduct of the research as a component of the sub-program of the collaborating senior staff member. These individuals, and their sources of other support, are listed in Table 2.

Table 2

Visiting Post-Doctoral Scientists on Project

Name	Other Sources of Support	Time Period
Charles L. Brewer (Ph.D., U. Arkansas, 1965) Assoc. Prof., Furman University	NSF Research Participation Program	Summer, 1969
Janice M. Erskine (Ph.D., U. Michigan, 1963) Asst. Prof., Humboldt State Col. (Calif.)	NSF Research Participation Program	Summer, 1970 Summer, 1971
David S. Gorfein (Ph.D., Columbia U., 1962) Assoc. Prof., New College (Fla.)	NSF Res. Part. Prg. NSF Spec. Fellow	Summer, 1968 1 Jan 69 - 31 Dec 69
Henry M. Halff (Ph.D., U. Texas, 1969) Asst. Prof., Univ. Illinois, Urbana	USPHS Post-Doctoral Fellow	1 Sep 69 - 31 Aug 70
John C. Jahnke (Ph.D., Northwestern U., 1955) Professor, Miami University (Ohio)	NIMH Spec. Fellow	1 Sep 67 - 1 Sep 68
David A. Johnson (Ph.D., Okla State U., 1969) Asst. Prof., Sweet Briar College (Virginia)	NSF Research Participation Program	Summer, 1970
Henry B. Loess (Ph.D., Univ. Iowa, 1952) Professor, College of Wooster (Ohio)	NSF Research Participation Program	Summer, 1968
Peter D. McCormack (Ph.D., Univ. Iowa, 1957) Professor, Carleton Univ. (Ontario)	Visiting Professor + Project Support	1 Jul 69 - 30 Jun 70
John A. McNulty (Ph.D., Univ. Toronto, 1963) Professor, Dalhousie Univ. (Nova Scotia)	Killam Senior Fellow (Dalhousie Univ.)	1 Sep 68 - 31 Jul 69
David J. Murray (Ph.D., Cambridge Univ., 1964) Asst. Prof., Queens Univ. (Ontario)	Lecturer Psychology + Project Support	1 Jul 68 - 31 May 69
Glen A. Raser (Ph.D., Iowa State Univ., 1970) Continuing as NIMH Post-Doctoral Fellow	NIMH Post-Doctoral Fellow	1 Sep 70 - 31 Aug 71
Addison E. Woodward (Ph.D., Univ. Toronto, 1968). Asst. Prof., Albion College (Michigan)	NSF Research Participation Program	Summer, 1970 Summer, 1971

Junior Staff

The junior scientific staff on the project were, with only one exception (Mrs. Rivka Fine, a full-time Research Assistant), graduate students in Experimental Psychology or Mathematical Psychology at the University of Michigan. However, these students fall into two classes: (a) those who have completed the requirements for a Ph.D. in Psychology with a dissertation based on project research, and (b) those who have not as yet done so. Those who have completed dissertations are listed in Table 3 in date order, along with information about their dissertation research and their present locations.

Table 3
Junior Staff Members Who Completed Doctoral Dissertations on Project Research

Name	Publ. Dissertation	Present Location
Reicher, G. M.	HPC TR #7, February, 1968	Asst. Prof., Univ. Oregon
Ligon, E.	HPC TR #8, May, 1968	Lecturer, Univ. Michigan
Triggs, T. J.	HPC TR #9, August, 1968	Bolt, Beranek and Newman
Tversky, B.	HPC TR #10, October, 1968	USPHS Post-Doctoral Fellow, Stanford University
Lively, B. L.	HPC TR #11, November, 1968	Asst. Prof., Bowdoin College
Swensson, R. G.	HPC TR #13, December, 1968	Bell Tel. Labs, Whippany, N.J.
Kamlet, A. S.	HPC TR #15, June, 1969	Bell Tel. Labs, Holmdel, N.J.
Pollatsek, A. W.	HPC TR #16, July, 1969	Asst. Prof., U. Massachusetts
Garsko[illegible], M. H.	HPC TR #17, August, 1969	
Shulman, H. G.	HPC TR #18, September, 1969	Asst. Prof., Ohio State U.
Gardner, G. T.	HPC TR #23, August, 1970	Asst. Prof., Univ. Michigan at Dearborn
Wattenbarger, B.L.	HPC TR #22, August, 1970	Bell Tel. Labs, Holmdel, N.J.
Adams, R. A. S.	HPC TR #24, September, 1970	Lecturer, Univ. New South Wales
Collins, A. M.	HPC TR #27, June, 1971	Bolt, Beranek and Newman
Cohen, V. V. R.	HPC TR #28, June, 1971	Cal. State College, Hayward
Gelfand, H.	HPC TR #29, June, 1971	
Roberts, K. H.	HPC TR #30, July, 1971	Asst. Prof., Univ. California at Los Angeles
Bennett, I. F.	HPC TR #32, August, 1971	Res. Assoc., Lehigh University
Bennett, R. W.	HPC TR #33, August, 1971	Asst. Prof., Lehigh University
Chananie, J. D.	Submitted, September, 1971	Univ. Southern California
Wichawut, C.	Submitted, September, 1971	Asst. Prof., Penn. State U.
Walter, D. A.	Submitted, September, 1971	Asst. Prof., Univ. Notre Dame

Other graduate students who have participated in the research program for some substantial portion of their time while in residence at the University are as follows: Robert L. Abramowitz*, Ted W. Allen*, Jonathan Brush, Stephen T. Carey, Arthur M. Glenberg*, William R. Graham, David E. Kieras*, Stephen A. Mackay*, Richard E. Mayer*, Brian K. Peterson, Donald J. Polzella*, Harvey A. Prussin, Richard A. Rasche, Stephen M. Reder, Janet K. Robinson*, Samuel M. Rubin (Deceased), Daniel A. Wagner*, William B. Whitten*, and Paul D. Winchester*. Those individuals whose names are followed by an asterisk (*) are currently continuing their graduate programs at the University of Michigan.

Consultants

During the four years of this contract, a number of psychologists whose experimental and theoretical work related closely to the work in progress have been brought to the Human Performance Center for one or two-day visits to consult on research problems. These are listed, along with their affiliations, in Table 4.

Table 4

Outside Consultants on the Project

Gordon H. Bower	Professor of Psychology, Stanford University
Robert G. Crowder	Assoc. Professor of Psychology, Yale University
James Deese	Professor of Psychology, Johns Hopkins University
Henry C. Ellis	Professor of Psychology, University of New Mexico
William K. Estes	Professor of Psychology, Rockefeller University
Murray Glanzer	Professor of Psychology, New York University
Phillip B. Gough	Professor of Psychology, University of Texas
David A. Grant	Professor of Psychology, University of Wisconsin
Chizuko, Izawa	Professor of Psychology, State Univ. New York-Buffalo
Stephen W. Keele	Assoc. Professor of Psychology, Univ. of Oregon
Geoffrey Keppel	Professor of Psychology, Univ. of Calif.-Berkeley
Marcel Kinsbourne	Prof. of Pediatrics & Neurology, Duke University
Walter Kintsch	Professor of Psychology, University of Colorado
Robert E. Morin	Professor of Psychology, Kent State University
Raymond S. Nickerson	Vice-President, Behavioral Science, Bolt, Beranek and Newman
Peter G. Polson	Assoc. Professor of Psychology, Univ. of Colorado
Michael I. Posner	Professor of Psychology, University of Oregon
Leo Postman	Professor of Psychology, Univ. of Calif.-Berkeley
Ernst Z. Rothkopf	Supervisor, Learn.&Instr. Process Res. Group, Bell Telephone Labs, Murray Hill, N. J.
Richard M. Shiffrin	Asst. Professor of Psychology, Indiana University
Saul Sternberg	Member Technical Staff, Bell Telephone Labs, Murray Hill, N. J.
Endel Tulving	Professor of Psychology, Yale University
Benton J. Underwood	Professor of Psychology, Northwestern University
Delos D. Wickens	Professor of Psychology, Ohio State University

PART III

TECHNICAL PROGRAM

The major product of this contract has been numerous communications of research findings and theoretical analyses of human information handling processes to the scientific community. These communications are listed in the following sections headed "Technical Reports" and "Presentations to Scientific Meetings." Sub-categories of the first section relate to the publication status of the technical reports as of the terminal date of the contract, 31 August 1971. Following these lists is a summary of "Major Accomplishments" under the contract.

Technical Reports

This list includes all formal technical reports supported by contract funds during the period 1 June 1967 to 31 August 1971. These reports are categorized according to whether (a) the basic work for the report was supported by the previous ARPA-AFOSR contract AF 49(638)-1235, which terminated 31 May 1967, but publication and distribution costs were supported by the present contract, (b) the technical report under the present contract has been published and copies have been or will be transmitted to ARPA, AFOSR, and the Defense Documentation Center prior to 1 October 1971 with funds supplied by the contract, (c) the technical report under the contract is "in press" and funds for publication costs must be obtained from other sources than the contract, and (d) the technical report of work on the contract has been submitted for publication, and will carry acknowledgement of contract support if and when published.

Throughout these lists of technical reports the project report number (e.g., 08773-15-J) is indicated in parentheses following the citation. These numbers match those reported as Originator's Report Number on DD Form 1473 as submitted with each report. Reports that have been published in two forms, once as a Human Performance Center Technical Report and later in a scientific journal, are listed once only (as the journal or book publication) with a reference to previous publication in HPC Technical Report form, even though the journal publication may be a substantial abridgment of the HPC Technical Report publication.

(a) Reports involving joint support of Contracts AF 49(638)-1235 and AF 49(638)-1736: The work represented in the following technical reports was accomplished under Contract AF 49(638)-1235, but publication costs were supported from AF 49(638)-1736. There are 12 technical reports in this category, of which 4 are journal publications of reports previously issued and distributed as Human Performance Center Technical Reports under Contract AF 49(638)-1235, and 8 were indicated as "in press" in the Final Report on that contract. These reports are not considered as products of the present contract in summary statements about the products of that contract.

Bernbach, H. A. Stimulus learning and recognition in paired-associate learning. Journal of Experimental Psychology, 1967, 75, 513-519. (08773-15-J) (An abridged version of a doctoral dissertation previously issued as University of Michigan Technical Report 05823-7-T, August, 1965.)

Crowder, R. G. Short-term memory for words with a perceptual-motor interpolated activity. Journal of Verbal Learning and Verbal Behavior, 1967, 6, 753-761. (08773-11-J) (An abridged version of a doctoral dissertation previously issued as University of Michigan Technical Report 05823-3-T, December, 1964.)

Egeth, H., & Smith, E. E. Perceptual selectivity in a visual recognition task. Journal of Experimental Psychology, 1967, 74, 543-549. (08773-14-J)

Goggin, J. P. First-list recall as a function of second-list learning method. Journal of Verbal Learning and Verbal Behavior, 1967, 6, 423-427. (08773-07-J)

Goggin, J. P. Retroactive inhibition with different patterns of interpolated lists. Journal of Experimental Psychology, 1968, 76, 102-108. (08773-13-J)

Martin, E. Stimulus recognition in aural paired-associate learning. Journal of Verbal Learning and Verbal Behavior, 1967, 6, 272-276. (08773-02-J)

Martin, E. Relations between stimulus recognition and paired-associate learning. Journal of Experimental Psychology, 1967, 74, 500-505. (08773-08-J)

Martin, E. Short-term memory, individual differences and shift performance in concept formation. Journal of Experimental Psychology, 1968, 76, 514-520. (08773-20-J)

Martin, E., & Roberts, K. H. Sentence length and sentence retention in the free-learning situation. Psychonomic Science, 1967, 8, 535-536. (08773-03-J)

Pachella, R. G., & Pew, R. W. The speed-accuracy trade-off in reaction time: The effect of discrete criterion times. Journal of Experimental Psychology, 1968, 76, 19-24. (08773-12-J)

Smith, E. E. Effects of familiarity on stimulus recognition and categorization. Journal of Experimental Psychology, 1967, 74, 324-332. (08773-06-J) (An abridged version of a doctoral dissertation previously issued as University of Michigan Technical Report 05823-9-T, December, 1965.)

Smith, E. E. Choice reaction time: An analysis of the major theoretical positions. Psychological Bulletin, 1968, 69, 77-110. (08773-16-J) (Published version of Human Performance Center Technical Report No. 6, January, 1967, 05823-13-T.)

(b) Technical reports published and distributed under the present contract: All technical reports listed here have been accomplished, published, and distributed under the provisions of Contract AF 49(638)-1736 during the period 1 June 1967 to 31 August 1971.

This list contains 57 technical reports, of which 33 are published as articles in scientific journals or chapter in scientific books, 17 are published as Human Performance Technical Reports and 7 are published as Human Performance Center Memorandum Reports. In this list are 19 technical reports that constitute doctoral dissertations in experimental or mathematical psychology at the University of Michigan (3 additional doctoral dissertations are listed in Section d as submitted for publication). These dissretations were accomplished as an integral part of the research program of the present contract, and with two exceptions (T. J. Triggs, Dr. Irwin Pollack, Chairman; R. G. Swensson, Dr. Ward Edwards, Chairman) senior staff of the project served as chairmen of the doctoral committees as follows: Dr. R. A. Bjork (A. W. Pollatsek); Dr. Judith Goggin (M. H. Carskof); Dr. Edwin Martin (A. M. Collins, K. H. Roberts, D. A. Walter, and C. Wichawut); Dr. Arthur W. Melton (R. A. S. Adams, R. W. Bennett, H. Gelfand, E. Ligon, B. L. Lively, G. M. Reicher, H. G. Shulman, and B. G. Tversky); Dr. Richard W. Pew (I. F. Bennett, J. D. Chananie, V. V. R. Cohen, G. T. Gardner, A. S. Kamlet and B. L. Wattenbarger).

Adams, R. A. S. Interference in short-term retention of discrete movements. Human Performance Center Technical Report No. 24, September, 1970. (Doctoral Dissertation) (08773-68-T)

Bennett, I. F. Spatial effects in visual selective attention. Human Performance Center Technical Report No. 32, August, 1971. (Doctoral Dissertation) (08773-87-T)

Bennett, R. W. III Theoretical implications of proactive interference in short-term memory. Human Performance Center Technical Report No. 33, August, 1971. (Doctoral Dissertation) (08773-88-T)

Bjork, R. A. Repetition and rehearsal mechanisms in models of short-term memory. In D. A. Norman (Ed.), Models of human memory. New York: Academic Press, 1970. (08773-63-B) (Published version of Human Performance Center Technical Report No. 14, 08773-39-T, May, 1969.)

Bjork, R. A. Positive forgetting: The noninterference of items intentionally forgotten. Journal of Verbal Learning and Verbal Behavior, 1970, 9, 255-268. (08773-66-J)

Bjork, R. A., & Allen, T. W. The spacing effect: Consolidation or differential encoding. Journal of Verbal Learning and Verbal Behavior, 1970, 9, 567-572. (08773-75-J)

Cohen, V. V. R. Short-term memory for quantitative information from three kinds of visual displays. Human Performance Center Technical Report No. 28, June, 1971. (Doctoral Dissertation) (08773-82-T)

Collins, A. M. The effect of visual stimulus traces on memory. Human Performance Center Technical Report No. 27, June, 1971. (Doctoral Dissertation) (08773-81-T)

Gardner, G. T. Spatial processing characteristics in the perception of brief visual arrays. Human Performance Center Technical Report No. 23, August, 1970. (Doctoral Dissertation) (08773-64-T)

Garskof, M. H. Short-term retention of paired associates as a function of instructions and retention method. Journal of Verbal Learning and Verbal Behavior, 1968, 7, 409-412. (08773-31-J)

Garskof, M. H. The effect of spacing and variation of repetition in short-term memory. Human Performance Center Technical Report No. 17, August, 1969. (Doctoral Dissertation) (08773-42-T)

Gelfand, H. Organization in free recall learning: Output contiguity and interresponse times as a function of presentation structure. Human Performance Center Technical Report No. 29, June, 1971. (Doctoral Dissertation) (08773-83-T)

Goggin, J. Retroactive interference with multiple interpolated lists. Journal of Experimental Psychology, 1969, 80, 483-488. (08773-44-J)

Goggin, J., & Martin, E. Forced stimulus encoding and retroactive interference. Journal of Experimental Psychology, 1970, 84, 131-136. (08773-60-J)

Goggin, J., & Stokes, C. Whole and part learning as a function of approximation to English. Journal of Experimental Psychology, 1969, 81, 67-71. (08773-45-J)

Greeno, J. G. Theory of graphs on sets with application to problem solving and understanding. Human Performance Center Memorandum Report No. 6, October, 1968. (08773-27-M)

Greeno, J. G. A cognitive interpretation of negative transfer and forgetting of paired associates. Human Performance Center Memorandum Report No. 9, November, 1969. (08773-51-M)

Greeno, J. G. Theoretical entities in statistical inference. Human Performance Center Memorandum Report No. 12, October, 1970. (08773-69-M)

Greeno, J. G. How associations are memorized. In D. A. Norman (Ed.), Models of human memory. New York: Academic Press, 1970. (Published version of Human Performance Center Technical Report No. 12, 08773-32-T, December, 1968.) (08773-71-B)

Halff, H. M. The differential effects of stimulus presentation during error- and success-feedback intervals in concept identification. Human Performance Center Memorandum Report No. 14, August, 1971. (08773-89-M)

Jahnke, J. C. The Ranschburg paradox. Human Performance Center Memorandum Report No. 5, July, 1968. (08773-22-M)

Jahnke, J. C., & Melton, A. W. Acoustic similarity and the Ranschburg phenomenon. Proceedings, American Psychological Association, 1968, 65-66. (08773-24-J)

Kahneman, D., Beatty, J., & Pollack, I. Perceptual deficit during a mental task. Science, 1967, 157, 218-219. (08773-04-J)

Kamlet, A. S. Processing of sequentially presented signals in information-combining tasks. Human Performance Center Technical Report No. 15, June, 1969. (Doctoral Dissertation) (08773-40-T)

Kammann, R., & Melton, A. W. Absolute recovery of first-list responses from unlearning during 26 minutes filled with an easy or difficult information processing task. Proceedings, American Psychological Association, 1967, 63-64. (08773-05-J)

Lachar, B., & Goggin, J. Effects of changes in word length on proactive interference in short-term memory. Psychonomic Science, 1969, 17, 213-214. (08773-54-J)

Ligon, E. The effects of similarity on very-short-term memory under conditions of maximal information-processing demands. Human Performance Center Technical Report No. 8, May, 1968. (Doctoral Dissertation) (08773-19-T)

Lively, B. L. The von Restorff effect in very-short-term memory. Human Performance Center Technical Report No. 11, November, 1968. (Doctoral Dissertation) (08773-29-T)

Loess, H., Brown, A., & Campbell, J. Cultural norms for items in 30 taxonomic categories. Psychonomic Monograph Supplement 1969, 3, 69-86. (08773-59-J)

Martin, E. Responses to stimuli in verbal learning. Human Performance Center Memorandum Report No. 3, October, 1967. (08773-09-M)

Martin, E. Recognition and correct responding mediated by first letter of trigram stimuli. (Supplementary Report) Journal of Verbal Learning and Verbal Behavior, 1968, 7, 703-704. (08773-34-J)

Martin, E. Stimulus meaningfulness and paired-associate transfer: An encoding variability hypothesis. Psychological Review, 1968, 5, 421-441. (08773-30-J)

Martin, E. Associative interference theory and spontaneious recovery. Human Performance Center Memorandum Report No. 10, November, 1969. (08773-52-M)

Martin, E. Toward an analysis of subjective phrase structure. Psychological Bulletin, 1970, 74, 153-166. (08773-74-J)

Martin, E. Verbal learning theory and independent retrieval phenomena. Psychological Review, 1971, 78, 314-322. (08773-90-J)

Martin, E., & Carey, S. T. Retroaction, recovery, and stimulus meaningfulness in the A-B, A-Br paradigm. American Journal of Psychology, 1971, 84, 123-133. (08773-80-J)

Martin, E., & Mackay, S. A. A test of the list-differentiation hypothesis. American Journal of Psychology, 1970, 83, 311-321. (08773-73-J)

Martin, E., & Melton, A. W. Meaningfulness and trigram recognition. Journal of Verbal Learning and Verbal Behavior, 1970, 9, 126-135. (08773-59-J)

Martin, E., Roberts, K. H., & Collins, A. M. Short-term memory for sentences. Journal of Verbal Learning and Verbal Behavior, 1968, 7, 560-566. (08773-25-J)

Martin, E., & Walter, D. A. Subject uncertainty and word-class effects in short-term memory for sentences. Journal of Experimental Psychology, 1969, 80, 47-51. (08773-38-J)

McCormack, P. D. Monitoring eye movements during the learning of paired-associate lists. Human Performance Center Technical Report No. 20, March, 1970. (08773-57-T)

Melton, A. W. The situation with respect to the spacing of repetitions and memory. Journal of Verbal Learning and Verbal Behavior, 1970, 9, 596-606. (08773-76-J)

Pew, R. W. The speed-accuracy operating characteristic. Acta Psychologica, 1969, 30, 16-26. (08773-43-J)

Pollatsek, A. W. Rehearsal, interference, and spacing of practice in short-term memory. Human Performance Center Technical Report No. 16, July, 1969. (Doctoral Dissertation) (08773-41-T)

Reicher, G. M. Perceptual recognition as a function of meaningfulness of stimulus material. Journal of Experimental Psychology, 1969, 81, 275-280. (08773-46-J) (An abridged version of a doctoral dissertation previously issued as Human Performance Center Technical Report No. 7, February, 1968, 08773-17-T.)

Roberts, K. H. Grammatical and associative constraints in sentence retention. Journal of Verbal Learning and Verbal Behavior, 1968, 7, 1072-1076. (08773-36-J)

Roberts, K. H. An investigation of paraphrasing: The effects of memory and complexity. Human Performance Center Technical Report No. 30, July, 1971. (Doctoral Dissertation) (08773-85-T)

Shulman, H. G. Encoding and retention of semantic and phonemic information in short-term memory. Journal of Verbal Learning and Verbal Behavior, 1970, 9, 499-508. (08773-77-J) (An abridged version of a doctoral dissertation previously issued as Human Performance Center Technical Report No. 18, September, 1969, 08773-47-T.)

Shulman, H. G. Similarity effects in short-term memory. Psychological Bulletin, 1971, 75, 399-415. (08773-84-J)

Shulman, H. G., & Martin, E. Effects of response-set similarity on unlearning and spontaneous recovery. Journal of Experimental Psychology, 1970, 86, 230-235. (08773-70-J)

Swensson, R. G. The elusive tradeoff: Speed versus accuracy in choice reaction tasks with continuous cost for time. Human Performance Center Technical Report No. 13, December, 1968. (Doctoral Dissertation) (08773-33-T)

Triggs, T. J. Capacity sharing and speeded reactions to successive signals. Human Performance Center Technical Report No. 9, August, 1968. (Doctoral Dissertation) (08773-23-T)

Tversky, B. G. Pictorial and verbal encoding in a short-term memory task. Perception and Psychophysics, 1969, 6, 225-233. (08773-49-J) (An abridged version of a doctoral dissertation previously issued as Human Performance Center Technical Report No. 10, October, 1968, 08773-28-T.)

Wattenbarger, B. L. The representation of the stimulus in character classification. Human Performance Center Technical Report No. 22, August, 1970. (Doctoral Dissertation) (08773-62-T)

Wichawut, C., & Martin, E. Selective stimulus encoding and overlearning in paired-associate learning. Journal of Verbal Learning and Verbal Behavior, 1970, 85, 383-388. (08773-72-J)

Wichawut, C., & Martin, E. Independence of A-B and A-C associations in retroaction. Journal of Verbal Learning and Verbal Behavior, 1971, 10, 316-321. (08773-86-J)

Woodward, A. E., & Bjork, R. A. Forgetting and remembering in free recall: Intentional and unintentional. Journal of Experimental Psychology, 1971, 89, 109-116. (08773-91-J)

(c) Technical reports in press: The following list includes technical reports of the present contract that are in press in the journal or report series indicated, will carry attribution of support by Contract AF 49(638)-1736, but costs of publication and distribution cannot be borne by contract funds because of time limitations.

Greeno, J. G. Utilization of cognitive structures in problem solving and reasoning. In K. Wexler (Ed.), Cognitive organization and behavior. Washington, D. C.: National Academy of Sciences, in press.

Martin, E. Stimulus component independence. Journal of Verbal Learning and Verbal Behavior, 1971, in press.

Mayer, R. E., & Greeno, J. G. Structural differences between learning outcomes produced by different instructional procedures. Journal of Educational Psychology, in press.

(d) Technical reports submitted for publication: The following list includes technical reports of the present contract that have been submitted for publication in the journal or report series indicated, and will carry attribution of support by Contract AF 49(638)-1736, but work involved in required revisions, if any, and costs of publication and distribution cannot be borne by contract funds because of time limitations.

Bjork, R. A. Serial position effects and control processes in free recall. Submitted to Journal of Verbal Learning and Verbal Behavior.

Chananie, J. D. Memory effects in visual search: The graticule. Submitted for publication as Human Performance Center Technical Report. (Doctoral Dissertation: Dr. R. W. Pew, Chairman)

Kieras, D., & Greeno, J. G. Memory retrieval and transformation of formulas in judgments of computability. Submitted to Journal of Cognitive Psychology.

Mayer, R. E., & Greeno, J. G. Memory retrieval and transformation of formulas in simple problem solving. Submitted to Journal of Cognitive Psychology.

Pachella, R. G., & Fisher, D. F. Hick's Law and the speed-accuracy trade-off in reaction time. Submitted to Journal of Experimental Psychology.

Raser, G. A. False recognition as a function of dimension of encoding and lag. Submitted to Journal of Experimental Psychology.

Walter, D. A. The role of acoustic and semantic dimensions of memory on sentence memory and comprehension. Submitted for publication as Human Performance Center Technical Report. (Doctoral Dissertation; Dr. Edwin Martin, Chairman).

Wattenbarger, B. L., & Pachella, R. G. The effect of memory load on reaction time in character classification. Submitted to Perception and Psychophysics.

Wichawut, C. Context-induced encoding variability and the effect of spacing of repetitions in continuous recognition memory. Submitted for publication as Human Performance Center Technical Report. (Doctoral Dissertation; Dr. Edwin Martin, Chairman).

Oral Presentations of Research Findings at Scientific Meetings

During the period of this contract there were 47 presentations of the findings at scientific meetings. These are listed below. There were, of course, many additional, less formal presentations of the work by senior staff of the project at many different Universities in the form of colloquia and seminar papers.

Bjork, R. A. Repetition and rehearsal mechanisms in models of short-term memory. Paper presented in Symposium on Models of Short-Term Memory, Mathematical Psychology Meetings, Stanford University, August, 1968.

Bjork, R. A. The short-term and long-term effects of recency in free recall. Paper presented at Psychonomic Society, St. Louis, November, 1968.

Bjork, R. A., & Abramowitz, R. L. The optimality and commutivity of successive intervals in short-term memory. Paper presented at Midwestern Psychological Association, Chicago, April, 1968.

Bjork, R. A., Abramowitz, R. L., & Krantz, J. H. Selective high-speed scanning of item sets in short-term memory. Paper presented at Midwest Mathematical Psychologists Meeting, Bloomington, April, 1970.

Carey, S. T., & Martin, E. Stimulus meaningfulness and spontaneous recovery: Single tests in a STM situation. Paper presented at Midwestern Psychological Association, Chicago, May, 1969.

Cohen, V. V. R. Short-term memory for quantitative information from visual displays. Paper presented at Psychonomic Society, San Antonio, November, 1970.

Cohen, V. V. R., & Pew, R. W. Small-sized target sets in visual search under accuracy set. Paper presented at Midwestern Psychological Association, Cincinnati, May, 1970.

Garskof, M. H. The effect of conceptually similar and different specific stimuli on the short-term retention of generic categories. Paper presented at Midwestern Psychological Association, Chicago, May, 1969.

Goggin, J., & Martin, E. Stimulus encoding and retroactive inhibition. Paper presented at Midwestern Psychological Association, Chicago, May, 1968.

Goggin, J., & Robinson, J. The effect of stimulus variation on the recall of generic stimuli. Paper presented at Midwestern Psychological Association, Chicago, May, 1969.

Goggin, J., & Robinson, J. Free recall as a function of stimulus variation and retention interval. Paper presented at Midwestern Psychological Association, Cincinnati, May, 1970.

Greeno, J. G. Psychological representation of structured knowledge. Paper presented at American Educational Research Association, Los Angeles, February, 1969.

Greeno, J. G. Time-sharing by subjects in paired-associate learning. Paper presented in Symposium on Distribution Effects in Learning and Memory, Midwestern Psychological Association, Chicago, May, 1969.

Greeno, J. G. Inferences about component processes in paired-associate memorizing. Paper presented at Symposium on Models for Memory, XIX International Congress of Psychology, London, England, August, 1969.

Greeno, J. G. A cognitive interpretation of negative transfer and forgetting of paired associates. Invited Research Address, American Psychological Association, Washington, D. C., September, 1969.

Jahnke, J. C., & Melton, A. W. Acoustic similarity and the Ranschburg phenomenon. Paper presented at American Psychological Association, San Francisco, August, 1968.

Jahnke, J. C., & Melton, A. W. An analysis of the Ranschburg effect. Paper presented at Psychonomic Society, St. Louis, November, 1968.

Kammann, R., & Melton, A. W. Absolute recovery of first-list responses from unlearning during 26 minutes filled with an easy or difficult information processing task. Paper presented at American Psychological Association, Washington, D. C., September, 1967.

Mackay, S. A., & Martin, E. Tachistoscopic manipulation of stimulus encoding variability in paired-associate learning. Paper presented at Midwestern Psychological Association, Chicago, May, 1968.

Martin, E. Word-class effects in sentence retention. Paper presented at Psychonomic Society, Chicago, October, 1967.

Martin, E. Stimulus factors in verbal transfer. Paper presented at American Association for the Advancement of Science, New York, December, 1967.

Martin, E. Subject uncertainty and word-class effects in sentence memory. Paper presented at Psychonomic Society, St. Louis, November, 1968.

Martin, E. An experimental denial of list-differentiation theory. Paper presented at Midwestern Psychological Association, Cincinnati, May, 1970.

Martin, E. Intra-sentence selective encoding. Paper presented at International Conference on the Psychology of Human Learning, Prague, Czechoslovakia, July, 1969.

Martin, E. Subjective phrase structure of English sentences. Paper presented at Psychonomic Society, St. Louis, November, 1969.

Martin, E., & Melton, A. W. Effect of spacing on recognition, accuracy and latency. Paper presented at Psychonomic Society, San Antonio, November, 1970.

Melton, A. W. Short-term memory: I. Interference effects, and short-term memory: II. Recognition memory. Invited lectures at NATO Advanced Studies Institute on Techniques and Results in the Assessment of Short-Term Memory, Cambridge, England, August, 1967.

Melton, A. W. Implications of proactive inhibition in short-term memory for the analysis of coding processes in memory. Paper presented at Symposium on Psychopathology of Memory, Dedham, Massachusetts, October, 1967.

Melton, A. W. Repetition and retrieval from memory. Paper presented at Fall Meeting of the National Academy of Sciences, Ann Arbor, Michigan, October, 1967.

Melton, A. W. Memory and the learning process. Invited address to the American Educational Research Association, Chicago, February, 1968.

Melton, A. W. The situation with respect to the effects of spacing of repetitions and memory. Paper presented as chairman and discussant in Symposium on Distribution Effects in Learning and Memory, Midwestern Psychological Association, Chicago, May, 1969.

Melton, A. W. Repetition and remembering. Presidential address before Division of Experimental Psychology, American Psychological Association, Washington, D. C., September, 1969.

Melton, A. W., & Brush, J. Effects of spacing of presentations on recognition time. Paper presented at Psychonomic Society, St. Louis, November, 1969.

Melton, A. W., & Shulman, H. G. Further studies of a distributed practice effect on probability of recall in free recall. Paper presented at Psychonomic Society, Chicago, October, 1967.

Pew, R. W. The speed accuracy operating characteristic. Paper presented at Donders Centenary Conference on Reaction Time, Eindhoven, Netherlands, July, 1968.

Pew, R. W. Toward a process-oriented theory of human skilled performance. Paper presented at Symposium on Tracking Skill, XIX International Congress of Psychology, London, England, August, 1969.

Polzella, D. J., & Martin, E. Methodological remarks on determining subjective phrase structure. Paper presented at Midwestern Psychological Association, Detroit, May, 1971.

Reder, S., & Bjork, R. A. Set differentiation in short-term memory. Paper presented at Psychonomic Society, San Antonio, November, 1970.

Roberts, K. H. The Close procedure and determinants of recall. Paper presented at Midwestern Psychological Association, Chicago, May, 1968.

Shulman, H. G. The effects of word and categorical repetitions on free recall. Paper presented at Midwestern Psychological Association, Chicago, May, 1968.

Shulman, H. G., & Martin, E. Effects of response set similarity on unlearning and spontaneous recovery. Paper presented at Midwestern Psychological Association, Cincinnati, May, 1970.

Walter, D. A. Effects of semantic context on short-term semantic and acoustic recognition memory. Paper presented at Midwestern Psychological Association, Detroit, May, 1971.

Walter, D. A., & Martin, E. Stimulus meaningfulness and spontaneous recovery of associations: Repeated tests in a stimulus recognition situation. Paper presented at Midwestern Psychological Association, Chicago, May, 1969.

Wattenbarger, B. L. Speed and accuracy set in visual search performance. Paper presented at Midwestern Psychological Association, Chicago, May, 1968.

Wichawut, C. Effects of degree of learning on cue selection in paired-associate learning. Paper presented at Midwestern Psychological Association, Cincinnati, May, 1970.

Wichawut, C., & Martin, E. Independence of A-B and A-C associations in retroaction. Paper presented at Midwestern Psychological Association, Detroit, May, 1971.

Woodward, A. E., & Bjork, R. A. Forgetting and remembering in free recall: Intentional unintentional. Paper presented at Midwestern Psychological Association, Cincinnati, May, 1970.

Major Accomplishments

Taxonomy of Information Handling Processes

A gross taxonomy of information handling tasks, as developed under the preceding Contract AF 49(638)-1235, differentiated between information-conserving tasks (one-to-one mapping of input stimuli and output responses, as in discriminative identification and short-term and long-term veridical recall of messages), information-reducing tasks (filtering tasks involving selective attention to and encoding of input information), and classification tasks (many-to-one mapping of input stimuli and output responses, as in categorizing tasks). However, the categories of this gross taxonomy--although useful as gross descriptors of human information processing tasks--are insufficient for prediction and control of performance.

Precise prediction and control of performance in information-processing tasks requires a process taxonomy, which in turn requires process theories. The gross taxonomy relates to objective input-output relations in various tasks; what is required are models of performance that specify the type and sequencing of the central dynamic operations (processes) the human imposes on the input (stimulus) and output (response) in the context of the skills, habits, and associations (the memory structure) extant in the individual operator. Substantial contributions have been made within the contract program to the specification of the process components of selective perception, short-term memory, and long-term memory (learning, transfer, forgetting). These contributions will be described in subsequent sections on those topics.

Selective Information Processing in Perception

The initial coding and transformation of sensory data for immediate or short-term utilization in the control of differential responding is the portion of the domain of "perception" stressed within this project. Data and theory about such processes appear to be most widely relevant to the performance of operators in man-machine systems. The work of the project has, in addition, focussed on four specific issues: (1) Perceptual selection, i.e., how the stimuli relevant for a particular performance are selected from irrelevant stimuli; (2) Perceptual encoding, i.e., the nature of the resulting encoded representation, and how that representation compares with memorial information with which it is to be compared or combined; (3) Speed-accuracy task demands; i.e., the effect of demands for performance speed on accuracy and on the nature of the encoding operations; and (4) Capacity limitations, i.e., the issue whether, when a series of perceptual judgments or responses must be made, the required operations can be conducted in parallel or must form a queue and be handled in series.

Perceptual selection. The efficiency of extraction of relevant information seems, based on current evidence, to be a function of the size, configuration and meaningfulness of the units in the display. Gardner (1970) has shown that under most conditions detection accuracy for tachistoscopic displays of alphabetical stimuli decreases as the number of letters in the display increases. These data are consistent with the interpretation that the initial encoding processes are capable of handling larger input units (i.e., the number of letters handled simultaneously) only with a reduced discriminative capacity for each letter

within a unit, although unlimited capacity models are not ruled out. Inge Bennett (1971) has shown that when stimulus-array size is held constant, the spatial configuration of the relevant stimulus letters within the array also affects processing efficiency. Thus, relevant letters were arranged either in adjacent positions (i.e., rows) or were scattered throughout the array. The interference produced by the irrelevant letters was much greater in the scattered arrays. It appears that irrelevant information can be rejected efficiently only when it is spatially separable from the relevant information. (See also, Chananie, Submitted, for evidence of improvement of visual search when target items remain fixed in spatial location from trial to trial.) Finally, if the letters in the stimulus array form a meaningful unit, as in a word, recognition accuracy is increased not only relative to non-meaningful arrays of the same size, but also to arrays consisting of single letters (Reicher, 1969).

These studies point toward a reformulation of perceptual selection problems in terms of the nature of the units that seem to yield efficient processing. If, as indicated, segmentation and organization of perceptual input takes place at very low, perhaps pre-attentive, levels of analysis and is followed by the processes that result in selection, then an understanding of this low-level organization is critical for a description of the processes in which selection actually occurs.

Perceptual encoding. Until recently, it was thought that the internal representation of a visual stimulus event maintained characteristics that were isomorphic with the visual properties of the stimulus. However, it now appears that the relation between the initial encoding

of a stimulus event and the processes that control the resulting internal representation used for comparisons with memorial information is more complex than previously thought, and poorly understood. Wattenbarger and Pachella (Submitted) have shown that a stimulus event may be classified relative to task demands before classification relative to information in short-term memory takes place, which suggests utilization of non-visual stimulus information in the initial encoding. Further, Wattenbarger (1970) has shown that, for alphabetic stimuli, the rate of scanning of short-term memory when the allograph (upper or lower case) of the letter is relevant is greater than the rate when the allograph is irrelevant. Thus, somewhere between the initial coding of sense data and the classification of a stimulus relative to information in short-term memory, the visual information must be recoded into verbal information, and the latter is given priority in making decisions about the incoming stimulus information.

At this time very little is known about the operations involved in the recoding of visual information into verbal information. However, Pachella and Selz (In preparation) have discovered that when subjects are forced to classify stimuli relative to information in short-term memory at high rates of speed, the duration of the initial encoding stages are reduced before the processes of scanning short-term memory are affected. Since the task could be carried out with either a visual or a verbal code, it seems likely that the processes that transform the visual image into a verbal code may be those affected by the speed stress. If such were the case, the speed stress would interact with the conditions under which the use of verbal codes gives more efficient performance.

Speed-accuracy task demands. When humans are required to perform perceptual-motor tasks with extreme emphasis on speed, the accuracy of their performance declines. A formal characterization of this speed-accuracy trade-off relation has been an object of this contract, as a continuation of work under Contract AF 49(638)-1235. The major theoretical (and practical) issue concerns the precision of the trade-off of speed and accuracy that an operator can make, with evidence currently supporting two diametrically opposed positions. One position, formally stated by Yellott (Journal of Mathematical Psychology, 1971) asserts that subjects can make only relatively imprecise adjustments of speed and accuracy. Swensson's (1968) study within the project supports this position. On the other hand, Pew (1969) has assembled and reviewed extensive evidence that subjects are capable of performing relatively precise adjustments of the trade-off. Pachella and Fisher (In press) have recently reported additional evidence favoring Pew's position. Although a generalized formal statement of the trade-off relation may be delayed for some time, it seems highly probable that the critical factors in the conflicting findings are (a) the difficulty or complexity of the task (less efficient trade-off in simple tasks), and (b) the strategies of the subjects.

Capacity limitations. If the perceptual system involved in making identification response to a series of input stimuli is a serial system, as maintained by A. T. Welford in his "single channel theory," there must be severe limitations on perceptual processing capacity. This theory postulates that when a second signal requiring processing arrives before the operations on a first signal are complete, the second

signal must wait for attention. The research by Triggs (1968) and Kamlet (1969) fails to confirm this theory. Instead, their findings argue for a parallel processing mode, which, although limited in capacity, does not have the severe limitations imposed by the serial mode.

Triggs (1968) arrived at this conclusion by showing that it is possible to manipulate the magnitude of the processing delay, when two stimuli come in rapid succession, by instructing the subject to direct primary attention toward rapid processing of either the first or the second stimulus. Kamlet (1969) employed an experimental design in which the first signal provided information about how to react to the second signal. By varying the time between the two signals, he inferred the time that must elapse before the information provided by the first stimulus could be utilized. It appeared that the two processing tasks could overlap to some extent, implying another violation of the strict single-channel model. Although some problems remain, it seems clear that Welford's conception must be modified to allow for the possibility of sharing of processing capacity over more than one task and, as suggested earlier, over more than one aspect of a single task.

Short-Term Memory

The emphasis within the project on short-term memory derives from the observation that (a) many human tasks are principally, if not solely, a matter of the efficiency with which an operator can receive information, hold it briefly in the presence of other required distracting activities, and retrieve it (or respond in terms of it) with high speed

and great accuracy, and (b) all human-information processing tasks involve such short-term holding and retrieval of information in some degree, such that the efficiency of short-term memory may be a critical factor in the efficiency of performance of the more complex task.

A number of different aspects of the short-term storage of information have been investigated. Major emphasis has been given to the memory for verbal messages (strings of alphanumeric elements, unrelated words, simple sentences), and on very-short-term memory (VSTM), i.e., memory over 2-3 sec or 5-6 intervening events. Emphasis on VSTM came about because work under the prior Contract AF 49(638)-1235 had convincingly demonstrated that retention over intervals from 3-4 sec to 30 sec was subject to the same kinds of interference from prior and interpolated learning as has been observed in long-term memory (LTM) for many years. Whether VSTM is also subject to these sources of interference is related to the question whether it is necessary to postulate the existence of two kinds of memory stores, "primary" or VSTM, and "secondary" or LTM.

The implication of the work on the project is that qualitative differences between VSTM and LTM in susceptibility to interference effects have not been observed, and that those differences that are observed appear to be a function of the rate of presentation of information or, more specifically, the time allowed for encoding of input information. Ligon (1968) demonstrated, with rapidly presented (3/sec) sequences of digits and letters, substantial interference in the cued retrieval of portions of messages when the portions of the message preceding and/or following the to-be-recalled segment were similar

in kind (letters interfered with letters more than digits interfered with letters). Also, the amount of interference increased as the number of prior or subsequent items increased. Other evidence for interference effects in VSTM or "immediate" memory for near memory-span lengths of messages has been presented and analyzed by Jahnke (1968) and Jahnke and Melton (1968) for messages that include a repeated element in them (e.g., 4852837), by Lively (1968) for messages that include a single element of a different class in them (e.g., 4852H37), and by Shulman (1970) for sequences of words that could be tested for visual, phonemic, or semantic encoding. Shulman (1971) has summarized the evidence on similarity effects in VSTM and STM. Not only acoustic (phonemic) similarity effects, but also semantic similarity effects may be shown in VSTM as well as STM. Such variation as is observed in the amount of phonemic and semantic similarity effects appears to be a function of the time allowed for processing the information into store and the type of processing emphasized. Simple rehearsal (saying over to oneself) may require less time than interpretive encoding (gaining meaning, thinking of associated words, etc.), so that very rapid presentation of to-be-remembered information results in a limitation, but not elimination, of semantic interference in retrieval. Shulman's experimental study (1970) supports this interpretation.

There is substantial evidence, as previously noted, for interference effects in STM based on the similarity of the last message presented--and now being recalled--and preceding messages that have been presented and recalled. This is properly described as intra-task proactive interference (PI), and is considered to have substantial significance

for the design of human information-processing tasks in which the operator serves as an information-transmission link for aperiodic messages that must be time-shared with some other demanding (i.e., distracting, or rehearsal-preventing) activity. Such proactive interference is absent in the recall of the very first message of a session, and the accuracy of recall of that first message is not significantly affected by the duration of the retention interval between 3-4 sec and 30 sec, even though recall at 3-4 sec is severely affected by the length of the message (See Melton, Final Report, Contract AF 49(638)-1235). However, accuracy of recall declines rapidly as the number of similar messages increases up to 4 or 5 and remains low thereafter unless there is an extended time interval in which no message is stored or there is "release" of PI resulting from a change in the character of the message being stored and recalled.

This build-up and release of proactive interference in STM, related to similarity variables in the messages, has been employed, particularly by D. D. Wickens of Ohio State University (see Psychological Review, 1970, 77, 1-15) to detect and identify the components of stimulus encoding processes and what is stored in memory. Wickens' analyses have been extended by Melton and R. Bennett (Unpublished) to show that the build-up and release of PI in STM holds for category (similarity) relations that are the product of a training program as well as for natural language category relations, and by Lacher and Goggin (1969) to show that such a presumably minor factor as the length of words is a similarity variable that produces a significant build-up in PI (when words are of the same length in successive messages) and a

significant release from PI (when the length of words is changed). However, the major contribution of the project to this problem has been made by R. Bennett (1971), who devised a new, recognition-memory test for PI in STM. His data show that PI effects previously observed in recall also occur in recognition memory. But of greater long-term significance is his conclusion, based on a detailed comparative analysis of alternative mathematical models of STM, that a satisfactory model of STM must include a competition-of-response mechanism or process to account for the observed PI in STM.

It is of obvious importance to specify the mechanisms by which items interfere with each other in memory. This has motivated work involving cuing-to-forget procedures (Bjork, 1970; Woodward & Bjork, 1971). There are circumstances under which an appropriate cue to forget information no longer needed facilitates memory for to-be-remembered information; in fact, in some circumstances such a cue completely eliminates proactive interference from the to-be-forgotten information. Studies designed to specify the conditions for effective intentional forgetting have shown that (a) the effectiveness of the cue to forget depends on the success of the individual in differentiating or segregating the to-be-forgotten and the to-be-remembered information, and (b) the to-be-forgotten information is not actually erased from memory but is, rather, made non-retrievable.

Other aspects of the problem of STM have been studied either for themselves or as incidental findings in the use of STM methods to study fundamental questions about the processing of information into memory. Collins (1971) tested the hypothesis that pre-perceptual visual stimulus

traces do not show the accumulation over repetitions characteristic of post-perceptual traces. A very small improvement in performance occurred over repetitions, but could be accounted for by uncontrolled rehearsal or attention to the repeated events; thus, the hypothesis was not disconfirmed. Adams (1970) examined the question whether interference occurs in the short-term retention of discrete movements, and if so, under what conditions. Large interference effects in retention of a movement were observed when other movements were interpolated before recall, and this interference could be related directly to the amount of motor output, rather than the similarity of the output. Factors in retention of discrete movements contrast sharply with factors in the retention of verbal information in a number of respects. Tversky (1968) examined the question whether the encoding modality of pictorial and verbal material can be manipulated by manipulating the subject's expectations of a pictorial or verbal test. The results demonstrated that no only can verbal materials be pictorially encoded (as when a word is encoded by an image of the object to which it refers) but also that an individual can encode both verbal and pictorial input optionally in verbal or pictorial form depending on expectation of conditions of efficient use of the encoding in short-term recognition judgments. Finally, Cohen (1971) used a short-term memory method, similar to that used in many studies within this project, to examine memory for quantitative information displayed by a digital counter, a moving scale, and a moving pointer. The digital display led to superior short-term retention, but there was evidence that under some conditions of interference from interpolated tasks the visual memory for the moving-pointer display augmented the verbal memory and improved recall.

Information Storage and Retrieval

Information encoding. The key determinant of the accessibility of information in memory appears to be the encoding of it at the time it is stored in memory. It is now widely recognized that a rigorous distinction must be made between the "nominal" information or stimulus input and the "functional" encoding of that nominal information in memory. In particular, the nominal information is subject to selective storage of portions or aspects of it, or there may be an interpretive bias reflected in the encoding. The latter is conceived of as a selection among optional interpretations, which may be normative or idiosynchratic alternatives, reflecting the biases imposed by the information processing context in which the nominal information occurs. An example of selective storage of nominal information in the encoding response is where an object with three critical features is coded into memory in terms of only one feature (or the number 106 is coded as "100"); an example of biased coding is where the information processing context of the word "bat" induces the storage of it as an item of sports equipment or as a flying mammal. The critical theoretical point in making this distinction between the nominal information and the information-as-coded (the encoding response to the nominal information) is that it is the latter, not the former, that gets stored in memory and that is the appropriate cue for retrieval of other encoded information associated with it through learning.

Retrieval and interference. An important implication of the distinction between nominal input information and the information-as-coded-into-memory is that different encoding responses can occur, given the

same nominal input. This "stimulus encoding variability" hypothesis has been examined by Martin (1968b), and has been shown to have important implications for the cuing of retrieval of information from memory (Martin, 1968a; Martin & Melton, 1970; Raser, Submitted; Wichawut & Martin, 1970; Wichawut, 1971) and for predicting and interpreting the loss of accessibility of some information resulting from the learning of other related information (Goggin & Martin, 1970). The encoding variability hypothesis has also led Martin (1971) to a critical analysis of contemporary interference theories of forgetting. He has proposed an alternative based on stimulus encoding theory, which makes use of a number of recent findings of this project on transfer of learning and forgetting (Greeno, 1969, 1970b; Martin, 1969; Martin & Mackay, 1970; Shulman & Martin, 1970; Wichawut & Martin, 1970, 1971). The thesis of this reintrepretation is that two distinct (and competing) behaviors may appear to be associated to the same nominal stimulus but are, in fact, associated to different functional encodings of that nominal stimulus, in part at least because the different responses bias the encoding of the nominal stimulus differently. The important practical consequence of this remodeling of the interference theory of forgetting is that it shifts the focus of both theoretic understanding and practical implementation to the perceptual end of the information-processing system, i.e., to the "normal" variability of and explicit manipulation of the information encoding process at the time of storage of information in memory.

Through the use of sophisticated analytical (mathematical) methods, Greeno (1970) has obtained evidence that learning of verbal associations

occurs in two relatively discrete stages. The first is the storage of the stimulus-response pair in memory (which is supporting evidence for the earlier statement that the response biases the encoding of the stimulus); the second is a process of learning to retrieve the response reliably when the stimulus is presented. This second stage adds emphasis to the importance of retrieval processes in the efficient utilization of memory and, like the stimulus encoding processes, deserves intensive theoretical and experimental development with a view to its implications for human information handling in a wide variety of tasks.

Mechanism of effectiveness of repetition. During the course of this contract it became increasingly evident that stimulus encoding variability might be a necessary condition for effective learning through repetition, at least for certain kinds of learning and certain conditions of attempted retrieval. The experimental findings favor, in a variety of learning tasks, the notion that the effectiveness of a repetition of input information improves memory for it as some function of the extent to which nominal input information occurs in information processing contexts that are sufficiently different to cause the encoding of it to be different on its several repetitions but not so different that the common referent is lost. The principle that appears to underlie this effect is that such encoding variability multiplies the linkages between the nominal information and the stable memory organization of the learner and in this way provides multiple access routes for the retrieval of the information from memory. This hypothesis is in sharp contrast to the widely accepted notion that the retrievability of information from memory is based on the "strength" of

an association, and that this strength accumulates as a function of repetitions under the "same" conditions, i.e., under conditions that maximize constancy of the encoding response.

The hypothesis that encoding variability, rather than encoding constancy, is what makes repetition effective developed within the project from the discovery by Melton that specific event memory (words) increased as the two occurrences of the event were separated by more and more other events (words). This has been shown to be a very robust phenomenon, in that it occurs with words and non-word trigrams, with different rates of presentation of words ranging from 2/sec to one word each 4.3 sec, and with visual or auditory presentation. A usual finding is that 20 other words between the first and second presentation of a word doubles the probability of later recall of that word, as compared with two back-to-back presentations of the word. Further increases in probability of recall have been observed as the number of intervening events was increased to 80. The interpretation of this finding is that the words intervening between the two presentations of the target word cause it to be coded differentially on its two occurrences, i.e., the information-processing contexts of the word become progressively dissociated the greater the number of intervening words (Melton, 1970).

Such beneficial effects of the spacing of information presentations on later recall have also been found in short-term memory experiments (Bjork & Allen, 1970; Pollatsek, 1969) where there is the clear implication that the beneficial effect of a second presentation on the later retention of the information is a direct function of the extent to which

the information cannot be retrieved from memory at the time of the second presentation. This failure of retrieval is interpreted as evidence of a shift in cuing conditions, and the beneficial effect of a new presentation of the information under these shifted cuing conditions is seen as favorable to the encoding variability interpretation of the effectiveness of repetition (Bjork, 1970; Bjork & Allen, 1970). If spacing in time produces such encoding variability, it should be possible to gain some of the effectiveness of spacing with back-to-back repetitions of an event, provided the learner is forced to encode the event differently on those two occasions; this has been confirmed, at least in part, in the study by Garskof (1969), and in some as-yet unpublished work by Goggin and Robinson.

The effects of spacing may not be limited to the spacing of objective repetitions of the information; there may be comparable effects of spacing the opportunities given to the learner to rehearse (Bjork, Submitted). Thus, it appears that a successful retrieval of information from long-term memory may facilitate later attempts to retrieve it from memory; whereas, retrieving information from very-short-term memory has little, if any, long-term benefits. This finding implies that a training routine that provides an immediate test of just-presented information, as in many programmed learning schedules, may be effective in achieving a transient performance criterion but may be ineffective for long-term retrieval of the information under varied cuing conditions.

Organization and structure in memory. It is now widely recognized that the encoding of information into memory is determined by the semantic organization of long-term memory and by the sequencing of the

information in sentences. A major effort within the project has been devoted to the recall of information received in the form of English sentences. Experimental results indicate that structural complexity of the message determines recall accuracy, that modifiers (adjectives, adverbs) are the weak spots, and that both of these phenomena are input phenomena, which is to say that structural determination and modifier effects occur at the time of receipt of the message as opposed to developing over a time delay (Martin, Roberts, & Collins, 1968; Martin & Walter, 1969; Roberts, 1969). Since a recall error is actually a "paraphrase" based on the semantic encoding of the presented sentence, Roberts (1971) undertook to discover the dominant characteristics of paraphrasing. Among the results: simple messages are complicated and complicated messages are simplified in paraphrasing; paraphrases judged most different in semantic intent from their original versions are those in which the verb phrase has been altered; lengthening and shortening the original message did not in themselves prejudice the paraphrase. In a doctoral thesis, Walter (Submitted) has shown that when a message does not make sense it is retained primarily in its acoustic form, but when it is plain English its acoustic representation is lost rapidly in favor of a semantic representation.

Developments of this sort rest strongly on the fact that the information input is a structured sequence. Accordingly, it is important to ascertain the nature of the structure. Traditional linguistics prescribes constituents and phrases of sentences, but Martin (1970) has developed an application of hierarchical clustering analysis and shown that ordinary users of the language do not view the structure of English

sentences as prescribed by linguistics. Thus a beginning has been made on discovering subjective, in-use organization of structured messages.

Other studies within the project were concerned with learning and recall of lists of words that had, or did not have, membership in common taxonomic categories (e.g., geographic features, animals, trees, etc.). It has been widely observed that even lists of "unrelated" words are organized into subjective units, as indexed by the consistency with which the words within the subjective units will be recalled adjacently. Such "clustering" is very greatly facilitated when lists contain words from the same taxonomic categories. The latter can be observed in recall following a single presentation of the list, but the Subjective Organization of unrelated words has required observation of consistency of recall patterns over repeated trials. In a major methodological study, Gelfand (1971) demonstrated that interresponse times during recall were very short between members of a subjective unit or cluster, and long between subjective units or clusters. Further, it was shown that such interresponse-time patterns on the first recall following a single presentation were predictive of the stable subjective units or clusters that would appear over repeated trials. This finding is believed to have wide utility in detecting organization units in recall, and therefore in the encoding of information during learning, even though only one recall trial following a single presentation is available for analysis. Loess, Brown, and Campbell (1969) provided a useful, new set of cultural norms for 30 taxonomic categories of words. These norms are being used in experimental analyses of semantic organization in learning and memory.

Problem solving and memory. The principal concern of Greeno, who joined the project in 1969, has been the relationship between the form of information in memory and the efficiency of problem solving in which that information must be used. Conceptual meaningfulness of stored information leads to fast decisions about the insufficiency of information in a problem statement for its solution, as compared with information stored in the form of uninterpreted formal symbols (e.g., letters). Thus, "understanding" pays off in speeded problem solving tasks where the operator must detect the need for more information before solution is attempted (Kieras & Greeno, Submitted). On the other hand, an initial hypothesis that the advantage of meaningful input to memory storage (of information required for problem solution) gained its advantage by including more relations between sets of concepts (Greeno, In press) was disconfirmed. Kieras and Greeno (Submitted) found that teaching formulas in a format designed to emphasize overall structure changed performance less than teaching in a format designed to emphasize relations within formulas. Further studies demonstrated that meaningful concepts may have their beneficial effects on judgments of computability of problems through the beneficial effects of such organization on retrieval of other required components of the problem from memory. It was shown that this beneficial effect of meaningfulness could be enhanced by use of formal notation that served to cue the operator to recognize variables belonging together.

The above findings about judgments of computability of problems, given the information presented, were strongly confirmed in experiments where complete solutions of problems were required. In addition, it was

shown that the organization of information used during training has large effects on problem solving with nonmeaningful (arbitrary) variables, but very small effects when variables have the form of meaningful concepts. Apparently, with concepts "understood" in a meaningful form, memory storage is accomplished in a way that permits easy recoding or retrieval from different substructure cues, while with nonmeaningful material, the functional cue must correspond exactly to the relations presented in training (Mayer & Greeno, Submitted). If, however, the information in memory is to be used only in a very restricted set of problems, as in making calculations from formulas, the optimal training is that which emphasizes simple calculations from not-necessarily meaningful formulas (Mayer & Greeno, In press.)

In this program, one study (Halff, 1971) has been made of the way in which informative feedback ("right" or "wrong") influences attainment of the correct solution. When feedback indicates that an operator's present idea is wrong, a considerable advantage is obtained by showing the stimulus situation in which the error occurred. When the operator's idea is correct, the assist to remembering the situation at the time the correct response was made has no effect on further performance.

PART IV

SUMMARY

This is the Final Technical Report on Contract AF 49(638)-1736 between the Advanced Research Projects Agency, Department of Defense, monitored by the Air Force Office of Scientific Research, and the Human Performance Center, Department of Psychology, University of Michigan, for research on Human Information Handling Processes during ther period 1 June 1967 to 31 August 1971. The report lists the products of contract work: 12 published technical reports reflecting work on this contract and earlier Contract AF 49(638)-1235; 57 technical reports published, 3 technical reports in press, 9 technical reports submitted for publication, and 47 oral presentations at scientific meetings. Major accomplishments are summarized under the general headings of (a) taxonomy of information handling processes, (b) short-term memory, and (c) storage and retrieval of information from memory.